

LDMOS TRANSISTOR STRUCTURE FOR IMPROVING HOT CARRIER RELIABILITY

Inventors: Douglas Brisbin, San Jose, CA
David Tsuei, Sunnyvale, CA
Alexander H. Owens, Los Gatos, CA
Andy Strachan, Santa Clara, CA

FIELD OF THE INVENTION

The invention relates to semiconductor devices, and particularly LDMOS transistors, and defines a method and device for improving hot carrier reliability.

DESCRIPTION OF RELATED ART

A power MOSFET is a high-voltage transistor that conducts large amounts of current when turned on. A lateral drift-diffused MOS (LDMOS), sometimes referred to as a lateral double diffused MOS, transistor is one type of power MOSFET. These devices are typically used at high voltages and currents (e.g. 20V and 10A/mm²). Under these conditions, as is discussed in more detail below, hot carrier effects occur and cause degradation of device parameters such as threshold voltage, gain and on-resistance (R_{dson}). For LDMOS transistors the most susceptible parameter to hot electron effects is the on-resistance. Elements and aspects of the LDMOS transistors are discussed in detail in numerous references including US Patent no. 6,566,710 entitled POWER MOSFET CELL WITH CROSSED BAR SHAPED BODY CONTACT AREA; and US Patent no. 6,548,839 entitled LDMOS TRANSISTOR STRUCTURE USING A DRAIN RING WITH A CHECKERBOARD PATTERN FOR IMPROVED HOT CARRIER RELIABILITY, both of these references are assigned to the same assignee as the present application, and are incorporated herein in their entirety.

An LDMOS transistor is commonly implemented with an array of alternating drain regions and alternating source regions rather than with a single drain region and a single source region. Each adjacent drain and source region can be referred to as a transistor cell. In the LDMOS transistor, the drain and source regions, each contribute a portion of the total

current output by the transistor.

FIG. 1 shows a plan view that illustrates a conventional checkerboard-patterned, n-channel LDMOS transistor 100. FIG. 2 shows a cross-sectional diagram of transistor array 100 taken along lines 2-2 of FIG. 1.

As shown in FIGs. 1-2, transistor 100, which is formed on a p- semiconductor substrate 110, includes an n+ buried layer 112 that is formed on substrate 110, and an n drift layer 114 that is formed on buried layer 112. Transistor 100 also includes an alternating pattern of n- field regions 116 and p- body regions 118 that are formed in layer 114.

Further, transistor array 100 includes a checkerboard pattern of drain regions 120 and source regions 122 of a first conductivity type (n+). The drain regions 120 are formed in n- regions 116 and the source regions 122 are formed in p- regions 118. Adjacent drain and source regions 120 and 122, in turn, define a number of transistor cells 124. All of the source regions 120 are connected in parallel utilizing a conduction, preferably metal (e.g. Al) source interconnect structure 146. Similarly, all of the drain regions 120 are connected in parallel utilizing a conductive preferably metal (e.g. Al), drain interconnect structure 144.

Thus, as shown in FIG. 1, except for the drain regions 120 on the outside edge of the pattern, each drain region 120 is a part of four transistor cells 124. Similarly, except for the source regions 122 on the outside edge of the pattern, each source region 122 is a part of four transistor cells 124. As a result, the center source region 122 shown in FIG. 1 receives current from four drain regions 120: the drain region directly above the center region, the drain region directly below the center region, the drain region directly left of the center region, and the drain region directly right of the center region.

As shown in Fig. 1 the source regions are generally square in shape having source region faces 148. These source region faces have an area which is determined by the source region face length (L_s) and by the depth of the source region, which is very shallow relative to the length of the face. Similarly, the drain regions are generally square in shape and have drain region faces 150. The drain region faces have an area which is defined by the drain region face length, and by the depth of the drain region, which is generally the same depth as the source region, and is very shallow relative to the drain region face length, L_d

Transistor array 100 additionally includes a number of p+ contact regions 126 that are formed in p- regions 118 adjacent to source region 122, and a number of n- regions 130 that

are formed in p- regions 118 adjacent to source region 122. Transistor array 100 also includes a number of field oxide regions FOX that surround drain regions 120, and a layer of gate oxide 132 that is formed over a portion of each body region 118 and an adjoining drift region 114. The field oxide region FOX separates drain region 120 from source region 122. (Drain region 120 and source region 122 can alternately be separated by a gap.)

Further, a gate 134 is formed between each drain and source region 120 and 122 on gate oxide layer 132 and the adjoining field oxide region FOX. In addition, an oxide spacer 136 is formed adjacent to each gate 134 over n- region 130. A salicide layer is also formed on each drain region 120 to form drain contacts 138, source region/contact region 122/126 to form source body contacts 140, and gate 134 to form gate contacts 142.

In operation, when the junction of drift region 114 and p- body region 118 of a transistor cell 124 is reverse biased (the combination of the regions 114 and 118 can be referred to as a channel region), such as when no voltage (or a low voltage or negative voltage is applied to the gate 134) and when a positive voltage is applied to drain contact 138 and ground is applied to source body contact 140 of the cell, an electric field is established across the junction. The electric field, in turn, forms a depletion region around the junction that is free of mobile charge carriers. Alternatively, when a positive voltage (such as 5 volts) is applied to the gate, the junction of the drift region 114 and the p-body region 118 is populated with carriers and is conducting with a relatively low on-resistance (r_{dson}).

In the reversed biased state, when the voltage on drain contact 138 of the cell is increased, the strength of the electric field is also increased. When the voltage on drain contact 138 exceeds a snapback voltage, mobile charge carriers in the depletion region, such as electrons from thermally-generated, electron-hole pairs, are accelerated under the influence of the electric field into having ionizing collisions with the lattice.

The ionizing collisions, in turn, form more mobile charge carriers which then have more ionizing collisions until, by a process known as avalanche multiplication, a current flows across the junction between drift region 116 and p- body 118. The holes that flow into p- body region 118 are collected by p+ contact region 126, while the electrons that flow into drift region 118 are collected by drain region 120. The electrons collected by the drain region 120 are subject to a relatively high electric potential by virtue of the voltage applied to the drain contact 138. As the electrons move closer to the drain region they are subjected to

increasing electric potential, and this increasing potential operates to accelerate the electrons thereby increasing their velocity. As the velocity of the electrons increases, the electrons create increasing amounts of ionizing collisions (impact ionization) with the atoms of the lattice structure. The impact ionization results in hot electron effects, or hot carrier effects. As the hot carrier effects increase due to increased impact ionization, the overall operation of the transistor cell and the overall transistor array can be degraded. It is believed that this degradation is the result of a number of factors, including the embedding of electrons in the gate oxide and the FOX areas.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a plan view illustrating a conventional checkerboard patterned, n-channel LDMOS transistor 100.

Fig. 2 is a cross-sectional diagram of transistor 100 taken along lines 2-2 of Fig. 1.

Fig. 3a is a top view of a portion of a conventional LDMOS cell.

Fig. 3b is a top view of a portion of an LDMOS cell of an embodiment of the invention.

Fig. 4a is a top view of a portion of a conventional LDMOS cell showing modeled current between a source region and a drain region of a conventional LDMOS cell.

Fig. 4b is a top view of a portion of an LDMOS cell showing modeled current between a source region and a drain region of an embodiment of the present invention of an LDMOS cell.

Fig. 5 is a table showing actual test data comparing the performance of an embodiment of the invention with a convention LDMOS transistor.

Fig. 6a is a simplified plan view showing a portion of a conventional LDMOS transistor.

Fig. 6b is a simplified plan view showing a portion of an LDMOS transistor of an embodiment of the invention.

DETAILED DESCRIPTION

Fig. 3a shows a top view of a portion of a source region 122 and a portion of a drain region 120 of a transistor cell. Fig. 3a does not show all the elements of the transistor such as

the poly gate 134 or the FOX region, so as to better illustrate elements of the cell disposed in the substrate. Fig. 4a displays model (simulation) data and corresponds to Fig. 3a, and shows curved lines 300, which represent current flowing from the drain region 120 to the source region 122, which corresponds, in part, to electrons moving from the source region to the drain region. The drain region 120 and the region 116 which have faces which are orientated toward the source region 122. The source region 122 has a source region face 148 which is orientated toward the drain region 120. In operation electrons converge on faces of the region 116 the drain region 120 which results in the concentration of the electrons increasing as the electrons get closer to the drain region 120. Further as the electron concentration increases, as the electrons converge on the drain region face 150 and region 116, the electrons are also subject to an increasing electric potential, as a result of the voltage applied to the contact 138 of the drain region 120. As discussed this concentration of mobile electrons with the increasing electric potential results in increasing electron velocity and in increasing numbers of impact ionizations which increases the hot carrier effects. An area of increased impact ionizations is represented by the area 204.

Fig. 3b shows a view of a portion of a cell of an embodiment of the present invention. As shown the length L_s of the source region face 148 is less than the length L_d of the drain region face 150. This is in contrast the prior LDMOS shown in Fig. 3a where the length L_s of the source region face 148 is greater than length L_d of the drain region face 150.

In one embodiment of the present invention the length L_s of the source region face 148 is approximately $2.75\ \mu\text{m}$ and the length L_d of the drain region face is approximately $5.4\ \mu\text{m}$. As a result the area on the drain region 120 which collects electrons is larger than the area of the source region 122 which emits electrons. Thus, the concentration of electrons in the area of the drain region 120, where the electric potential is high, is less than the concentration of electrons in the area of the source region where the electric potential is less than the electric potential in the area of the drain region.

Fig. 4b displays model (simulation) data and corresponds to Fig. 3b and shows curved lines 302 which represent current flowing from the drain region 120 to the source region 122 (which corresponds to electrons flowing from the source to the drain). As is represented by the area 304 the concentration of electrons in the area of the drain region 120 and the region 116 is reduced relative to concentration of the electrons for the prior device shown in

Fig. 3a. This reduction in concentration of electrons in the area drain region results in less impact ionizations, reducing the hot carrier degradation effects.

This reduction in hot carrier effects by reducing the concentration of electrons in the area of the drain region 120, achieved by increasing the length of the drain region face 150 relative to the source region face 148, has significant benefits in improving the hot carrier performance of the LDMOS transistor.

One of the most apparent benefits of increasing the length of the drain region face 150 relative to the source region face 148 is shown in the degradation of the R_{dson} overtime as the LDMOS is subject to gate and drain voltage stress conditions. For example, Fig. 5 shows actual test data for a CMOS LDMOS transistor where an electric potential of 2.42 volts is applied to the gate 134 and a potential of 24 volts is applied to the drain contact 138 and the voltage at the source contact is approximately 0 (zero) volts. The vertical axis 500 in Fig. 5 shows the percentage of degradation in R_{dson} and the horizontal axis 502 shows the amount of time the LDMOS is subjected to the stress condition. Line 504 shows the degradation of R_{dson} for a device where the drain region and the source region are of equal area (equal lengths for the source region face and drain region face, and substantially the same depths for the source region and drain regions). Line 506 corresponds the degradation R_{dson} for a LDMOS device where the length of the drain region is twice that of the length of the source region face. As is shown in Fig. 5 the LDMOS having the longer drain region face can withstand much longer periods of stress and still not have as much degradation in the R_{dson} as the LDMOS device where the drain region face and the source region face are the same length. In fact, as shown in Fig. 5 the device having the longer drain region face shows approximately 50 times greater performance in R_{dson} degradation over a device where the drain region face and the source region face are equal. This means that LDMOS device having a longer drain region face can provide a much longer operational life in terms of maintaining a desired R_{dson} consistency relative to a conventional LDMOS device.

Fig. 6a shows a simplified plan view of a portion of a conventional LDMOS transistor. As shown in Fig. 6a the length L_d for the face of the drain region 120 is about 70% of the length L_s of a face for the source region 122. The polygate 134 is shown between the alternating source regions 122 and of the alternating drain regions 120. Arrows 602

represent electrons flowing from the source to the drain. As shown the arrow indicate that electrons will become increasing more concentrated as the approach the face of the drain region 120. Fig. 6b shows a simplified plan view of an embodiment of an LDMOS transistor of the present invention. As shown in Fig. 6b the length L_d for the face of the drain region 120 is about twice the length L_s of a face for the source region 122. The polygate 134 is shown between the alternating source regions 122 and of the alternating drain regions 120. Arrows 602 represent electrons flowing from the source to the drain. As shown the arrow indicate that electrons will become increasingly more spread out as they approach the face of the drain region 120.

Although only specific embodiments of the present invention are shown and described herein, the invention is not to be limited by these embodiments. Rather, the scope of the invention is to be defined by these descriptions taken together with the attached claims and their equivalents.